CHAPTER 2

NSF EQUIPMENT VERIFICATION TESTING PLAN MEMBRANE FILTRATION FOR THE REMOVAL OF MICROBIOLOGICAL AND PARTICULATE CONTAMINANTS

Prepared by:
NSF International
789 Dixboro Road
Ann Arbor, MI 48105

TABLE OF CONTENTS

Page

1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN 2-6

2.0 INTRODUCTION 2-6

3.0 GENERAL APPROACH 2-7

4.0 OVERVIEW OF TASKS 2-8

4.1 Membrane Flux and Recovery 2-8
4.2 Cleaning Efficiency 2-8
4.3 Finished Water Quality 2-8
4.4 Reporting of Membrane Pore Size 2-8
4.5 Membrane Module Integrity 2-8
4.6 Data Management 2-9
4.7 QA/QC 2-9
4.8 Microbial Removal (Optional) 2-9
4.9 Raw Water Pretreatment (Optional) 2-9

5.0 TESTING PERIODS 2-9

6.0 DEFINITION OF OPERATIONAL PARAMETERS 2-10

6.1 Filtrate 2-10
6.2 Feedwater 2-10
6.3 Filtrate flux 2-10
6.4 Specific flux 2-10
6.5 Membrane fouling 2-10
6.6 Transmembrane pressure 2-11
6.7 Temperature Adjustment for Flux Calculation 2-11
6.8 Feedwater System Recovery 2-11
6.9 Membrane Element Recovery 2-11

7.0 TASK 1: MEMBRANE FLUX AND OPERATION 2-12

7.1 Introduction 2-12
7.2 Experimental Objectives 2-12
7.3 Work Plan 2-12
7.4 Analytical Schedule 2-13
7.4.1 Operational Data Collection 2-13
7.4.2 Feedwater Quality Limitations 2-14
7.5 Evaluation Criteria and Minimum Reporting Requirements 2-15

TABLE OF CONTENTS (continued)

		Page
8.0	**TASK 2: CLEANING EFFICIENCY**	2-15
8.1	Introduction	2-15
8.2	Experimental Objectives	2-15
8.3	Work Plan	2-15
8.4	Analytical Schedule	2-16
	8.4.1 Sampling	2-16
	8.4.2 Operational Data Collection	2-16
8.5	Evaluation Criteria and Minimum Reporting Requirements	2-16
9.0	**TASK 3: FINISHED WATER QUALITY**	2-17
9.1	Introduction	2-17
9.2	Experimental Objectives	2-17
9.3	Work Plan	2-18
9.4	Analytical Schedule	2-20
	9.4.1 Feed and Filtrate Water Characterization	2-20
	9.4.2 Water Quality Sample Collection	2-20
	9.4.3 Feedwater Quality Limitations	2-21
	9.4.4 (Optional Task) Turbidity Spiking	2-21
	9.4.5 (Optional Task) Removal of Simulated Distribution System (SDS) Disinfection By-Product (DBP) Precursors	2-23
9.5	Evaluation Criteria and Minimum Reporting Requirements	2-23
10.0	**TASK 4: REPORTING OF MEMBRANE PORE SIZE**	2-24
10.1	Introduction	2-24
10.2	Experimental Objectives	2-24
10.3	Work Plan	2-24
11.0	**TASK 5: MEMBRANE INTEGRITY TESTING**	2-24
11.1	Introduction	2-24
	11.1.1 Direct Monitoring Methods	2-24
	11.1.2 Indirect Monitoring Methods	2-24
11.2	Experimental Objectives	2-24
11.3	Work Plan	2-25
	11.3.1 Direct Monitoring Methods	2-25
	11.3.2 Indirect Monitoring Methods	2-25
11.4	Evaluation Criteria and Minimum Reporting Requirements	2-26

TABLE OF CONTENTS (continued)

Page

12.0 TASK 6: DATA HANDLING PROTOCOL 2-26

12.1 Introduction 2-26
12.2 Experimental Objectives 2-26
12.3 Work Plan 2-26

13.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL 2-27

13.1 Introduction 2-27
13.2 Experimental Objectives 2-27
13.3 Work Plan 2-27
13.4 Daily QA/QC Verifications 2-28
13.5 QA/QC Verifications Performed Every Two Weeks 2-28
13.6 QA/QC Verifications Performed Each Testing Period 2-28
13.7 On-Site Analytical Methods 2-28
13.7.1 pH 2-28
13.7.2 Temperature 2-28
13.7.3 Turbidity Analysis 2-28
13.7.3.1 Bench-Top Turbidimeters 2-29
13.7.3.2 In-Line Turbidimeters 2-29
13.7.4 Particle Counting 2-29
13.7.4.1 Bench-Top Particle Counters 2-30
13.7.4.2 In-Line Particle Counters 2-32
13.8 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance 2-32
13.9 Microbial Parameters: Total Coliform and Heterotrophic Plate Counts 2-33
13.10 Inorganic Samples 2-33
13.11 Simulated Distribution System (SDS) Test Protocol 2-33
13.11.1 Chlorine Stock Solution Preparation 2-34
13.11.2 Preparation of Additional Chemicals 2-34
13.11.3 Sample Collection and Incubation 2-34
13.11.4 Analytical Measurements 2-34

14.0 TASK 8: MICROBIAL REMOVAL (OPTIONAL) 2-34

14.1 Introduction 2-34
14.2 Experimental Objectives 2-35
14.3 Work Plan 2-35
14.3.1 Organisms Employed for Pilot-Scale Challenge Experiments 2-35
14.3.2 Microbial Seeding Protocols 2-36
14.4 Analytical Schedule 2-37
14.4.1 Water Quality Sampling 2-37
14.4.2 Operational Data Collection 2-37
14.5 Evaluation Criteria and Minimum Reporting Requirements 2-37

TABLE OF CONTENTS (continued)

Page

15.0 RAW WATER PRETREATMENT (OPTIONAL) 2-37

15.1 Introduction 2-37
15.2 Experimental Objectives 2-37
15.3 Work Plan 2-38
15.4 Analytical Schedule 2-38
15.4.1 Raw, Pretreated Feed and Filtrate Water Characterization 2-38
15.4.2 Water Quality Sample Collection 2-38
15.4.3 Feedwater Quality Limitations 2-39
15.5 Evaluation Criteria and Minimum Reporting Requirements 2-39

16.0 OPERATION AND MAINTENANCE 2-40

16.1 Maintenance 2-40
16.2 Operation 2-40

17.0 REFERENCES 2-42

APPENDIX 2A - STATE SPECIFIC VERIFICATION TESTING REQUIREMENTS 2-43

1.0 APPLICATION OF THIS NSF EQUIPMENT VERIFICATION TESTING PLAN

This document is the NSF Equipment Verification Testing Plan for membrane filtration. This Testing Plan is to be used as a guide in the development of the Field Operations Document for testing of membrane filtration equipment, within the structure provided by the NSF Protocol document for particulate removal. Refer to the "Protocol For Equipment Verification Testing For Physical Removal of Microbiological And Particulate Contaminants" for further information. It should be noted that this Equipment Verification Plan is only applicable to pressure-driven membrane processes. It does NOT apply to:

- electrically-driven,
- thermally-driven, or
- concentration-driven membrane processes.

In order to participate in the equipment verification process for membrane filtration, the equipment Manufacturer and their designated Field Testing Organization shall employ the procedures and methods described in this test plan and in the referenced NSF Protocol Document as guidelines for the development of Field Operations Document. The Field Operations Document should generally follow those Tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each Task should consist of the following sections:

- Introduction
- Objectives
- Work Plan
- Analytical Schedule
- Evaluation Criteria

Each Field Operations Document shall include Tasks 1 to 7. Task 8, microbial seeding studies and Task 9, raw water pretreatment, are not mandatory. For example, some Manufacturers may wish to become NSF-verified for removal capabilities of *Giardia, Cryptosporidium* and/or viruses. In this case, the protozoa and/or virus seeding components of Task 8 should become a part of the Field Operations Document.

2.0 INTRODUCTION

Pressure-driven membrane processes are currently in use for a broad number of water treatment applications ranging from removal of microbial contaminants such as *Giardia* and *Cryptosporidium*, to removal of natural organic matter contributing to disinfection by-product (DBP) formation. Typically, ultra low pressure membrane processes, such as microfiltration (MF) and ultrafiltration (UF) are employed to provide a physical barrier for removal of microbial and particulate contaminants from drinking waters. Higher pressure membrane applications such as nanofiltration and reverse osmosis are typically employed to achieve differing degrees of removal of total organic carbon (TOC) hardness ions, and other inorganic constituents such as salt species, in some applications. Nonetheless, this NSF Equipment Verification Testing Plan is applicable to any pressure-driven membrane process.

This plan is applicable to any membrane geometry as long as it is adequately described by the Manufacturer. Various membrane geometries are currently employed for water treatment applications including:

- spiral-wound (SW),
- hollow-fiber (HF),

- tubular,
- cassette,
- cartridge,
- flat sheet.

3.0 GENERAL APPROACH

This NSF Equipment Verification Testing Plan is broken down into 9 tasks, as shown in the Experimental Matrix, Table 1. As noted above, Tasks 1 to 7 shall be performed by any Manufacturer wanting the performance of their equipment verified by NSF. Tasks 8 and 9 are optional and can be implemented at the Manufacturer's discretion. The Manufacturer's designated Field Testing Organization shall provide full detail of the procedures to be followed in each Task in the Field Operations Document. The Field Testing Organization shall specify the operational conditions to be verified during the Verification Testing Plan. All filtrate flux values shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 68 °F or liters per square meter per hour (L/(m^2-hr)) at 20 °C.

The total verification testing plan shall be performed over a one month period (not including time for system shakedown and mobilization). At a minimum, one one-month periods of verification testing shall be conducted in order to provide equipment testing information.

Table 1
Task Descriptions

Task	Testing Periods (minimum)	Issue	Test
Membrane Verification Testing Study			
1 Membrane flux and recovery	1	Rate of specific flux decline	Evaluate productivity at selected set of operational conditions
2 Cleaning efficiency	1	Cleaning efficiency	Clean system to evaluate flux recovery
3 Finished water quality	1	Finished water quality and rejection capabilities	Measure water quality & rejection capabilities
4 Maximum pore size reporting	--	Reporting of 90% and maximum pore size	Report 90% and maximum pore size for the membrane tested
5 Membrane Integrity Testing	1	Integrity of membrane surface	Investigate integrity of membrane surface
6 Data handling protocol			
7 QA/QC			
8 Microbial Removal	optional	Removal of protozoa, bacteria, virus or surrogates	Conduct seeding experiments using MS2 virus, Giardia and/or Crypto
9 Raw water pretreatment	optional	Pretreatment techniques that are not considered necessary	Demonstrate membrane performance after pretreatment and determine efficacy of pretreatment

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the required and optional tasks to be included in the membrane verification testing program.

4.1 Membrane Flux and Recovery

The objective of this task is to evaluate membrane operation. Membrane productivity will be evaluated in relation to feedwater quality resulting from seasonal changes. The relative rates of flux decline and rejection capabilities will be used, in part, to evaluate operation of the membrane equipment under the flux conditions to be verified and at the seasonal conditions of raw water quality and temperature.

4.2 Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after membrane flux decline has occurred. The objective of this task is to evaluate the efficiency of the membrane cleaning procedures recommended by the Manufacturers. The fraction of specific flux which is restored following a chemical cleaning and after successive filter runs will be determined.

4.3 Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the membrane system. Multiple water quality parameters will be monitored during each of the four one-month testing periods. The mandatory water quality monitoring parameters shall include: turbidity, particle concentrations, coliforms and heterotrophic plate count bacteria populations. Others water quality parameters will be optional, such as total suspended solids, TOC, UV absorbance (at 254 nm wavelength), and DBP formation potential. A basic goal of this Task is to confirm that membrane treated waters meet EPA filtered water quality goals described in the SWTR. Water quality produced will be evaluated in relation to feedwater quality and operational conditions.

4.4 Reporting of Membrane Pore Size

Membranes for particle and microbial removal do not have a single pore size, but rather have a distribution of pore sizes. For example, a nominally rated 0.1 μm MF membrane may have pores ranging from 0.08 μm to 0.4 μm. Membrane rejection capabilities are thus limited by the maximum membrane pore size. The objective of this task it to report the 90% and maximum membrane pore size of the membranes employed in field operations.

4.5 Membrane Module Integrity

A critical aspect of any membrane process is the ability to verify that a membrane process is producing a specified water quality on a continual basis. For example, it is important to know whether the membrane is providing a constant barrier to protozoan oocysts such as *Cryptosporidium*. The objective of this task is to evaluate the integrity monitoring method for the membrane system. Membrane integrity shall be evaluated based on the method selected by the Field Testing Organization.

4.6 Data Management

The objective of this task is to establish effective field protocol for data management at the field operations site and for data transmission between the Field Testing Organization and the NSF.

4.7 QA/QC

An important aspect of verification testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during membrane equipment verification testing.

4.8 Microbial Removal (Optional)

The objective of this task, which is optional, is to evaluate microbial removal capabilities by seeding the systems with target organisms which shall include, but are not limited to selected protozoa and viruses. Removal capabilities will be evaluated in relation to operational conditions and the state of fouling of the membrane. The introduction of surrogates for protozoa and viruses may be allowed only when peer-reviewed studies and proven methodologies have shown the relationship between surrogates and target microorganisms.

4.9 Raw Water Pretreatment (Optional)

Most membrane processes that are employed for particle and microbial removal require no pretreatment, except for pre-screening, and therefore require no optional pretreatment testing per the requirements of this test plan. Furthermore, in cases where a pretreatment technique is considered an integral part or inseparable part of the function of the membrane system, no additional testing of system pretreatment capabilities would be necessary. However, some Manufacturers may wish to employ an optional pretreatment technique that does not represent an integral part of the membrane technology for removal of microbiological and particulate contaminants. Such optional pretreatment may be employed to extend membrane operational time or remove selected contaminants.

The objective of this raw water pretreatment task is to evaluate the efficacy of raw water pretreatment for improvement of membrane operation or removal of selected contaminants. The specific goals of this task will be to evaluate raw water pretreatment required prior to membrane filtration and to evaluate any changes in treated water quality associated with raw water pretreatment.

5.0 TESTING PERIODS

The required tasks of the NSF Equipment Verification Testing Plan (Tasks 1 through 7) are designed to be completed over a minimum of one verification testing period of 30 days, not including mobilization, shakedown and start-up. Membrane testing conducted beyond the testing period may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. Many of the tasks presented as Tasks 2 through 7 can be performed concurrent with Task 1, the flux and operational testing procedures. Optional Task 8 may also be conducted during the testing period. However, Task 9 shall be performed in an additional month of testing.

Additional verification testing periods may be necessary to verify the manufacturer's claims, such as in the treatment of surface water where additional testing during each season may assist in verifying a claim. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's claims. For example, a good challenge for a membrane would be a testing period during which the feedwater exhibits low temperature, high turbidity and/or natural organic matter. Although one testing period satisfies the minimum requirement of the ETV program, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined in Initial Operations. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of 30 days. The purpose of the 30 day test period is to demonstrate the ability of the equipment to meet the water quality goals specified by the Manufacturer, the product water recovery and the rate of flux decline observed over the 30 day period of operation.

6.0 DEFINITION OF OPERATIONAL PARAMETERS

6.1 Filtrate: Water produced by the membrane filtration process.

6.2 Feedwater: Water introduced to the membrane module.

6.3 Filtrate Flux: The average filtrate flux is the flow of product water divided by the surface area of the membrane. Filtrate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

where J_t = filtrate flux at time t (gfd, L/(h-m2)
Q_p = filtrate flow (gpd, L/h)
S = membrane surface area (ft^2, m^2)

It should be noted that gfd and L/(h-m2) shall only be used as units of flux.

6.4 Specific Flux: The term specific flux is used to refer to filtrate flux that has been normalized for the transmembrane pressure. The equation used for calculation of specific flux is given as follows:

$$J_{tm} = \frac{J_t}{P_{tm}}$$

where J_{tm} = specific flux at time t (gfd/psi, L/(h-m2)/bar)
J_t = filtrate flux at time t (gfd, L/(h-m2))
P_{tm} = transmembrane pressure (psi, bar)

Specific flux results shall always be reported with indication of the time interval after initiation of the experimental test run.

6.5 Membrane Fouling: A reduction in filtrate flux that can be restored by mechanical or chemical means is termed "reversible" fouling. In contrast, "irreversible fouling" is defined as a permanent loss in filtrate flux capacity that cannot be restored. The fouling of membranes designed for particle or microbial removal is primarily attributed to deposition of materials on the membrane surface and/or in the membrane pores.

6.6 Transmembrane Pressure: The average transmembrane pressure is calculated:

$$P_{tm} = \frac{(P_i + P_o)}{2} - P_p$$

where P_{tm} = transmembrane pressure (psi, bar)
P_i = pressure at the inlet of the membrane module (psi, bar)
P_o = pressure at the outlet of the membrane module (psi, bar)
P_p = filtrate pressure (psi, bar)

6.7 Temperature Adjustment for Flux Calculation: Temperature corrections to 20°C for transmembrane flux shall be made to correct for the variation of water viscosity with temperature. A specific, empirically derived equation developed by the membrane manufacturer may be used to provide temperature corrections. Alternatively, the following equation by Streeter and Wiley (1985) may be employed:

$$J_{tm}\ (at\ 20°C) = \frac{Q_p \times e^{-0.0239} \times (T - 20)}{S}$$

where J_{tm} = instantaneous flux (gfd, L/(h-m2))
Q_p = filtrate flow (gpd, L/h)
T = temperature, (°F, °C)
S = membrane surface area (ft^2, m^2)

6.8 Feedwater System Recovery: The recovery of filtrate from feedwater is given as the ratio of filtrate flow to feedwater flow:

$$\%\ System\ Recovery = 100 \times \left| \frac{Q_p}{Q_f} \right|$$

where Q_p = filtrate flow (gpd, L/h)
Q_f = feed flow to the membrane (gpd, L/h)

6.9 Membrane Element Recovery: The recovery of filtrate from total recirculation influent water is given as the ratio of filtrate flow to the sum of feedwater flow and recycle flow:

$$\%\ Element\ Recovery = 100 \times \left| \frac{Q_p}{Q_f + Q_r} \right|$$

where Q_p = filtrate flow (gpd, L/h)
Q_f = feed flow to the membrane (gpd, L/h)
Q_r = recycle flow (gpd, L/h)

7.0 TASK 1: MEMBRANE FLUX AND OPERATION

7.1 Introduction

Membrane operation will be evaluated in this task, with quantification of membrane flux decline rates and product water recoveries. The rates of flux decline will be used to demonstrate membrane performance at the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the Field Testing Organization in terms of a temperature-corrected flux value (e.g., gfd at 68 °F or L/(m^2-hr) at 20 °C) before the initiation of the Verification Testing Program.

The rate of specific flux decline is a function of water quality and operational conditions. In this task, water quality shall be monitored and operational conditions varied depending upon membrane flux decline profiles. Flow and pressure data shall be collected to quantify the loss of productivity in terms of rate of specific flux decline. A lower rate of specific flux decline implies that a longer operational run will be achieved by the membrane system.

7.2 Experimental Objectives

The objectives of this task are to demonstrate: 1) the appropriate operational conditions for the membrane equipment; 2) the product water recovery achieved by the membrane equipment; and 3) the rate of flux decline observed over extended membrane filtration operation. Raw water quality shall be monitored (Task 3) during each seasonal one-month testing period at a minimum, in order to track any significant variations that could impact rates of membrane flux decline.

It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the Field Testing Organization, as pertains to filtrate flux and transmembrane pressure. Verification of membrane operation shall also apply to operating conditions that are considered less stringent than those conditions tested; examples would include lower flux conditions and higher cross-flow velocities.

7.3 Work Plan

Determination of optimal membrane operating conditions for a particular water can typically require as long as one year of operation. For this task the Field Testing Organization shall specify the operating conditions to be evaluated in this Verification Testing Plan and shall supply written procedures on the operation and maintenance of the membrane treatment system. The Field Testing Organization shall also specify the termination criteria for their particular membrane equipment. For example, the termination criteria may consist of an 80% decline in specific flux, or increase in transmembrane pressure to a specific value. In this task, each set of operating conditions shall be maintained for the one-month testing period (continuous 24-hour operation). The Field Testing Organization shall specify the primary filtrate flux at which the equipment is to be verified.

After set-up and shakedown of membrane equipment, membrane operation should be established at the flux condition to be verified. The membrane system shall be operated as shown schematically in Figure 1 for a minimum of one month. If substantial specific flux decline of the membrane occurs at the specified flux before the one-month operating period is complete, chemical cleaning shall be performed and adjustments to the operational strategy shall be made (such as a decrease in transmembrane flux or an increase in backwash frequency, if applicable). Decisions on adjustments shall be made based upon the Manufacturer's experience and consultation with the NSF-qualified Field Testing Organization conducting the study. At a minimum, the membrane shall be chemically cleaned according to the Manufacturer specifications at the conclusion of the one month period. At this time, the cleaning efficiency will be determined per Task 2.

This NSF Membrane Verification Testing Plan has been written with the aim to balance the costs of verification with the benefits of testing membrane filtration over a wide range of operating conditions. Given that it may take as long as a month and longer to observe significant flux decline in a membrane system, examination under a wide range of operating conditions would be prohibitively expensive for the membrane Manufacturer. Therefore, this Verification Testing Plan requires that one set of operating conditions be tested for a one-month testing periods. It shall be furthermore understood that beyond the single set of verification operating conditions, membrane operation that occurs at a lower flux, a lower recovery, or a higher cross-flow velocity shall also constitute a verifiable condition.

In order to establish appropriate conditions of flux, recovery, backwash frequency and duration the manufacturer may have some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the verification testing.

Testing of additional operational conditions may be included in the year-long verification testing program at the discretion of the Manufacturer and their designated Field Testing Organization. However, testing of alternate additional operational conditions shall be performed by including additional one-month testing periods beyond the one month required by the Verification Testing Plan.

Additional months of testing may also be included in the Verification Testing Plan in order to demonstrate membrane performance under different feedwater quality conditions. For membrane filtration, extremes of feedwater quality (e.g., low temperature, high turbidity) are the conditions under which membranes are most prone to rapid flux decline and to failure. The Field Testing Organization shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional one-month testing period, as required above for each additional set of operating conditions.

The testing runs conducted under this task shall be performed in conjunction with Tasks 2, 3, 5 and the optional Tasks 8 and 9. With the exception of the additional testing periods conducted at the Field Testing Organization's discretion, no additional membrane test runs are required for performance of Tasks 2, 3, 5, 8 or 9.

7.4 Analytical Schedule

7.4.1 Operational Data Collection

Measurement of membrane feedwater flow and filtrate flow (recycle flow where applicable), system pressures and feedwater temperature shall be collected at a minimum of 2 times per day. Table 2 presents the operational data collection schedule. Measurement of feedwater temperature to the membrane shall be made daily in order to provide data for correction of transmembrane flux.

In an attempt to calculate costs for pilot-scale operation of membrane equipment, power costs for operation of the membrane equipment shall also be closely monitored and recorded by the Field Testing Organization during each testing period. Power usage shall be estimated by inclusion of the following details regarding equipment operation requirements: (pumping requirements, size of pumps, nameplate voltage, current draw, power factor, chemical usage, etc.). In addition, measurement of power consumed shall be provided by information on current draw and power consumption. Chemical usage shall be quantified by recording day tank concentration, daily volume consumption and unit cost of chemicals. No additional operational data shall be required by Tasks 2 through 4 unless specifically stated.

Table 2
Operational Data Collection Schedule

Location		Minimum Frequency
Raw		
	Flow	2/day
	Feedwater Temperature	1/day
Single Stage Membrane Processes		
	Influent module/vessel pressure	2/day
	Effluent module/vessel pressure	2/day
	Filtrate pressure	2/day
	Filtrate flow	2/day
Multiple Stage Membrane Processes		
	Stage 1 Influent module pressure	2/day
	Stage 1 Effluent module pressure	2/day
	Stage 1 Feed flow	2/day
	Stage 1 Filtrate pressure	2/day
	Stage 1 Filtrate flow	2/day
	Stage 2 Influent module pressure	2/day
	Stage 2 Effluent module pressure	2/day
	Stage 2 Feed flow	2/day
	Stage 2 Effluent module flow	2/day
	Stage 2 Filtrate pressure	2/day
	Stage 2 Filtrate flow	2/day
	Crossflow velocity	2/day

Note: The Field Testing Organization should adapt the operational data collection location to the particular geometry of the membrane system.

7.4.2 Feedwater Quality Limitations

The characteristics of feedwaters used during the testing period (and any additional one-month testing periods) shall be explicitly stated in reporting the membrane flux and recovery data for each season. Accurate reporting of such feedwater characteristics as temperature, turbidity, and total suspended solids (TSS) is critical for the Verification Testing Program, as these parameters may substantially influence the range of achievable membrane performance on a seasonal basis. In addition, accurate reporting of water quality characteristics such as pH, alkalinity, and total organic carbon (TOC) shall be reported on a monthly basis to provide a general background on the source water character and quality for each testing period. More frequent monitoring of these parameters may be performed if desired by the Manufacturer or recommended by FTO.

7.5 Evaluation Criteria and Minimum Reporting Requirements

- Transmembrane pressure (P_{tm})

⇒ Plot graph of transmembrane pressure over time for each 30 day period of operation

- Rate of specific flux decline

⇒ Plot graph of specific flux normalized to 20°C over time for each 30 day period of operation

- Cleaning efficiency

⇒ Provide table of intervals between chemical cleaning episodes and efficiency of cleaning achieved following each 30 day period of operation

8.0 TASK 2: CLEANING EFFICIENCY

8.1 Introduction

Following the test runs of Task 1, the membrane equipment may require chemical cleaning to restore membrane productivity. The number of cleaning efficiency evaluations shall be determined by the rate of specific flux decline of the membrane during the test period. At a minimum, one cleaning shall be performed at the conclusion of the required testing. In the case where the membrane does not fully reach the operational criteria for termination as specified by the Manufacturer and their designated Field Testing Organization in Task 1, chemical cleaning shall be performed after the 30 days of operation, with a record made of the operational conditions before and after cleaning.

8.2 Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning for restoring finished water productivity to the membrane systems. The intent of this task is to confirm that standard Manufacturer-recommended cleaning practices are sufficient to restore membrane productivity for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the recommendations of the Manufacturer; this task is considered a "proof of concept" effort, not an optimization effort. It should be noted that cleaning solution selection is typically feedwater quality specific. The testing plan should permit evaluation of cleaning solutions that are considered optimal for water being treated. If the manufacturer determines that a pre-selected cleaning formulation is not effective, the testing plan should allow the Manufacturer to modify it.

8.3 Work Plan

The membrane systems may experience substantial specific flux decline during the membrane test runs conducted for Task 1. At the conclusion of the test period, membranes shall be utilized for the cleaning assessments herein. No additional experiments shall be required to produce specific flux decline such that chemical cleaning evaluations be performed. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the Manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the initial conditions of specific flux recovery and rejection capabilities shall be tested.

The Manufacturer and their designated Field Testing Organization shall specify in detail the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- cleaning chemicals
- quantities and costs of cleaning chemicals
- hydraulic conditions of cleaning
- duration of each cleaning step
- initial and final temperatures of chemical cleaning solution
- quantity and characteristics of residual waste volume to be disposed

In addition, detailed procedures describing the methods for pH neutralization of the acid or alkaline cleaning solutions should be provided along with information on the proper disposal method for regulated chemicals. A description of all cleaning equipment and its operation shall be included in the Field Operations Document.

8.4 Analytical Schedule

8.4.1 Sampling

The pH, turbidity and TDS of each cleaning solution shall be determined and recorded during various periods of the chemical cleaning procedure. In addition, in the case that the cleaning solution employs an oxidant, such as chlorine, the concentration of the oxidant both before and at the end of the cleaning should be measured. Notes recording the visual observations (color, degree of suspended matter present) shall also be provided by the Field Testing Organization. No other water quality sampling shall be required.

8.4.2 Operational Data Collection

Flow, pressure, and temperature data shall be collected during the cleaning procedure if possible and shall be recorded immediately preceding system shutdown due to substantial membrane flux decline; flow, pressure, and temperature data shall also be collected immediately upon return to membrane operation, after chemical cleaning.

8.5 Evaluation Criteria and Minimum Reporting Requirements

At the conclusion of each chemical cleaning event and upon return to membrane operation, the initial condition of transmembrane pressure, recovery and temperature shall be recorded and the specific flux calculated. The efficacy of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficacy achieved during previous cleaning

evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible loss of specific flux and projections for usable membrane life.

Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1) The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (Js_f) and the initial specific flux (Js_i) measured for the subsequent filtration run:

$$Recovery\ of\ Specific\ Flux = 100 \times \left| 1 - \frac{Js_f}{Js_i} \right|$$

where: Js_f = Specific flux (gfd/psi, L/(h-m2)/bar) at end of current run (final)
Js_i = Specific flux (gfd/psi, L/(h-m2)/bar) at beginning of subsequent run (initial).

2) The loss of specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (Js_i) divided by the specific flux (Js_{io}) at time zero, as measured at the initiation of the first filtration run in a series:

$$Loss\ of\ Original\ Specific\ Flux = 100 \times \left| 1 - \frac{Js_f}{Js_{io}} \right|$$

where: Js_{io} = Specific flux (gfd/psi, L/(h-m2)/bar) at time zero point of membrane testing

The minimum reporting requirements shall include presentation of the following results:

- Flux recovery
- ⇒ Provide table of post cleaning flux recoveries during each 30 day period of operation
- Cleaning efficacy
- ⇒ Provide table of cleaning efficacy indicators described above for chemical cleaning procedures performed during each 30 day period of operation
- Assessment of irreversible loss of specific flux and estimation of usable membrane life for costing purposes

9.0 TASK 3: FINISHED WATER QUALITY

9.1 Introduction

Water quality data shall be collected for the feedwater and membrane filtrate water as shown in the sampling schedule Table 3, during the membrane test runs of Task 1. At a minimum, the required sampling schedule shown in Table 3 shall be observed by the Field Testing Organization on behalf of the Manufacturer. Water quality goals and target removal goals for the membrane equipment shall be recorded in the Field Operations Document.

9.2 Experimental Objectives

The objective of this task is to assess the ability of the membrane equipment to meet the water quality goals specified by the Manufacturer. A list of the minimum number of water quality parameters to be monitored

during equipment verification testing is provided in the Analytical Schedule section below and in Table 3. The actual water quality parameters selected for testing shall be stipulated by the Field Testing Organization in the Field Operations Document.

9.3 Work Plan

Many of the water quality parameters described in this task shall be measured on-site by the NSF-qualified Field Testing Organization (refer to Table 4). Analysis of the remaining water quality parameters shall be performed by a state-certified or third party- or EPA-accredited analytical laboratory. The methods to be used for measurement of water quality parameters in the field are described in the Analytical Methods section below and in Table 4. The analytical methods utilized in this study for on-site monitoring of feedwater and filtrate water qualities are described in Task 7, Quality Assurance/ Quality Control (QA/QC). Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

Table 3
Water Quality Sample Schedule

		Single Stage Process			Multiple Stage Processes				
					Stage 1			Stage 2	
Parameter	Sampling Frequency	Feed	Filtrate	Back-wash Waste	Feed	Filtrate	Concentrate	Filtrate	Backwash Waste
On-Site Analytes									
pH	Twice/week	1	0	0	1	1	1	1	1
Temperature	Daily	1	0	0	1	0	0	0	0
Turbidity	Daily	2	C[1]	2	2	C[1]	2	C[1]	2
Particle counts	Daily	2	C[1]	0	2	C[1]	1	C[1]	1
Laboratory Analysis									
Alkalinity	Monthly	1	1	0	1	1	1	1	1
Total/calcium hardness	Monthly	1	1	0	1	1	1	1	1
TDS	Once/2	1	1	0	1	1	1	1	1
TSS	Once/2	1	1	1	1	1	1	1	1
Total coliforms	Weekly	1	1	1	1	1	1	1	1
HPC	Weekly	1	1	0	1	1	1	1	1
TOC	Monthly*	1	1	0	1	1	1	1	1
UVA	Monthly*	1	1	0	1	1	1	1	1
SDS Testing (Optional)									
Total THMs	Monthly	1	1	0	1	1	0	1	0
HAA6	Monthly	1	1	0	1	1	0	1	0

C[1] continuous monitoring * more frequent monitoring may be performed at the discretion of the Manufacturer or FTO.

Table 4. Analytical Methods

Parameter	Facility	*Standard Methods*[1] number or Other Method Reference	EPA Method[2]
General Water Quality			
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Calcium Hardness	Lab	3500-Ca D	
Total Suspended Solids	Lab	2540 D	
Total Dissolved Solids	Lab	2540 C	
Particle Characterization			
Turbidity Bench top	On-Site	2130 B / Method 2	180.1
Turbidity In Line	On-Site	Manufacturer	
Particle Counts Bench top	On-Site	Manufacturer	
Particle Counts In Line	On-Site	Manufacturer	
Organic Compound Characterization			
Total organic carbon	Lab	5310 C	
UV_{254} absorbance	Lab	5910 B	
Total Trihalomethanes (TTHMs)	Lab		524.2; 502.2
Haloacetic Acids (HAA6)	Lab	6251B	552.1
Microbiological			
TC and HPC	Lab	9215 B	
Cryptosporidium	Lab	NSF and EPA may consider alternative methods if sufficient data on precision, accuracy, and comparative studies are available for alternative methods.	Draft EPA 1622, Korich, 1993/ see also 40 CFR 141.74 Appendix D
MS2 virus	Lab		EPA ICR Method for Coliphage Assay, 1996

Notes:
1) Standard Methods Source: 18th Edition of Standard Methods for the Examination of Water and Wastewater, 1992, American Water Works Association.
2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

For the water quality parameters requiring analysis at a state-certified or third party- or EPA-accredited laboratory, water samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the state-certified or third party- or EPA-accredited, off-site laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

9.4 Analytical Schedule

9.4.1 Feed and Filtrate Water Characterization

At the beginning of the testing period at a single set of operating conditions (and thereafter with indicated frequency), the raw water and filtrate water shall be characterized by measurement of the following water quality parameters (as indicated in Table 3):

- alkalinity (once per month)
- hardness (once per month)
- total suspended solids (once every two weeks)
- total dissolved solids (once every two weeks)
- total organic carbon (monthly)
- $UV_{254\ nm}$ absorbance (monthly)
- Total coliform (TC) and heterotrophic plate count (HPC) bacteria (once per week)
- temperature (daily)
- pH (twice per week)
- filtrate water turbidity and particle concentrations (twice daily)
- feed (and concentrate) water turbidity and particle concentrations (twice daily)

9.4.2 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during the period of membrane testing, as required in Table 3. For verification of particulate removal, turbidity and particle concentrations in filtrate waters shall be monitored continuously using either batch or in-line analytical instruments. Grab samples of feed waters to the membrane system shall be measured by the NSF-qualified Field Testing Organization twice daily for turbidity and particle concentrations using bench-top analytical equipment. The specific particle size ranges to be monitored by both in-line and bench-top analytical equipment during the verification testing are indicated in Task 7, the QA/QC section.

Water quality parameters including pH and temperature shall be monitored daily. Total suspended solids shall be monitored every other week and results of this analysis will be used to construct a mass balance of suspended solids through the membrane system. Optional monitoring of organic water quality parameters such as TOC and UV_{254} absorbance shall be performed on a monthly basis to evaluate rejection of organics by the membrane. Additional sampling and data collection may be performed at the discretion of the Field Testing Organization. Sample collection frequency and protocol shall be defined by the Field Testing Organization in the Field Operations Document.

On a weekly basis, samples of raw and filtrate waters shall be collected for analysis of indigenous bacterial densities including: total coliform (TC) and heterotrophic plate count (HPC). Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to the state-certified or third party- or EPA-accredited analytical laboratory. Samples shall be processed for analysis by the state-certified or third party- or EPA-accredited laboratory

within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities will be reported as colony forming units per milliliter (cfu/mL).

9.4.3 Feedwater Quality Limitations

The characteristics of feedwaters encountered during the testing period shall be explicitly stated in reporting the membrane flux and recovery data. Accurate reporting of such feedwater characteristics as temperature, turbidity, total suspended solids, pH, alkalinity and hardness is critical for the Verification Testing Program, as these parameters can substantially influence membrane performance on a seasonal basis.

9.4.4 (Optional Task) Turbidity Spiking

If the anticipated turbidity at the selected site does not challenge the system to the limits of its performance capabilities, an optional turbidity augmentation procedure may be implemented after the 30 days of verification testing has been completed. A procedure for turbidity spiking was published in *Journal AWWA* in December, 1993, pp. 39-46 by Logsdon et al. A spiking procedure based on the published technique is described in the following paragraphs. (In this NSF International document, when the word "tank" is used, this term includes a storage tank, an above-ground swimming pool of appropriate size, an earthen basin having a plastic liner, or any other device or means of holding large volumes of water.)

To spike turbidity, use of a local turbidity source is recommended. This could consist of sediments taken from the bottom of a river or lake, or natural soil of the type likely to erode into nearby watercourses and cause turbid waters. For testing done in many locations in the United States where row crop agriculture is practiced, topsoil could be used to prepare a suspension for turbidity spiking, because topsoil is a major contributor to turbid runoff as a result of heavy rains in such locations. Topsoil or sediments would be expected to contain some natural organic matter, and as such would enable the FTO to produce a turbidity suspension typical for much of the turbid runoff found in the United States.

The soil or sediments that will be used to prepare a suspension for turbidity spiking should be screened through a three inch screen to remove rocks, for protection of pumps that will be used to mix soil and water.

After screening, soil or sediment should be added in a batch tank having a capacity in the range of 400 to 1000 gallons. Mixing can be accomplished by using a pump with a flow capacity, expressed in gallons per minute, of about 10 percent of the batch tank volume, expressed in gallons. For a 400 gallon batch tank, a 40 gpm pump theoretically could pump one tank volume in 10 minutes. Use of a trash pump or dewatering pump capable of pumping very muddy water or suspensions of water and mud is recommended. The mixture of water and soil or sediment should be recirculated for about six to eight hours. The action of the pump impeller will help to break up soil particles to smaller sizes that do not settle rapidly.

After the turbidity slurry has been mixed as described above and then settled for one hour to allow small gravel, sand, and grit to settle to the bottom of the batch tank, the slurry can be transferred to a very large tank having the capacity in the range of 10,000 to 15,000 gallons. The diluted suspension should be

stirred or recirculated using a gasoline-powered portable pump of the kind used for dewatering at project construction sites, or an electric powered pump of equivalent flow capacity. The objective is to mix the water and slurry with a turnover time of about one hour. This mixing should be done for about six to eight hours, followed by two hours of quiescent settling for removal of the larger particles that would settle of their own accord during treatment. After settling, the turbidity suspension can be blended into feed water to make a more turbid feed water, or depending on the size of the treatment equipment being evaluated, and the length of the filter run, the turbidity suspension in the large tank might be used directly as feed water. If the turbidity suspension was to be used directly, more uniform turbidity could be attained by transferring the suspension to a second large tank that could be continuously stirred.

Depending on the number and duration of filter runs for which highly turbid water will be needed, sequential use of two large tanks may be appropriate. In such a situation, one large tank would be used for stirring and settling the turbidity slurry, while the second large tank would be used as the source of turbid water for spiking or as the source of feed water.

As an alternative to the use of the 10,000 to 15,000 gallon tanks described above, a second tank in the size range of 400 to 1000 gallons could be used. In this case, the suspension that had been mixed in the first 400 to 1000 gallon tank would be settled for two hours in the original tank, and about 80 percent of the contents would be decanted from the first tank to the second tank, leaving the sediments on the bottom undisturbed. The second tank should be stirred to maintain the turbidity-causing particles in suspension. The suspension that has been transferred to the second tank could be fed as a concentrated suspension and thoroughly mixed into the source water to create the turbid feed water. In this approach to turbidity spiking, an in-line mixer should be used to ensure effective mixing of the turbidity suspension and the source water. Sampling of feed water for turbidity analysis should be done only after the spiked turbidity suspension is thoroughly mixed into the feed water. After the turbidity suspension has been transferred to the second tank where the suspension can be used for spiking, preparation of another batch of turbidity suspension could begin again in the first tank.

The size of the tanks and the amount of soil or sediment slurry originally prepared in the highly concentrated form in the first mixing tank (the 400 to 1000 gallon tank described above) may be influenced by the rate of flow of the package treatment equipment being tested, and by the level of turbidity the FTO is trying to attain. Use of treatment equipment with larger flows, and selection of high turbidity goals may result in the need for bigger tanks and pumps and the use of considerably more soil, silt, or sediment. An estimate of the amount of soil could be made by estimating the mass concentration of suspended solids needed to produce a desired turbidity. In making such an estimate, though, the FTO should consider that a substantial portion of the soil might not be broken up into particles so fine that they do not settle out in the recommended settling times. Therefore, soil usage estimates based on suspended solids would understate actual soil requirements.

The turbid water fed in the treatment testing could be characterized by particle counting, in addition to turbidity measurement. In many cases this would require dilution of the turbid samples. A simpler test would be to simply collect a sample of the water and place it in a 1000 mL graduated cylinder, and then record the location of the interface between turbid water and clearer water over a period of three to five hours as the suspension settles. A turbidity suspension that settled very slowly would be representative of turbid water containing fine particulate matter that would be found in many surface waters after heavy runoff.

9.4.5 (Optional Task) Removal of Simulated Distribution System (SDS) Disinfection By-Product (DBP) Precursors

During the steady-state operation of the testing period, optional SDS DBP testing will be performed on the membrane feedwater and the filtrate product water in order to determine the precursor removal capabilities of the membrane system. SDS DBP testing will be used to estimate by-product formation (primarily trihalomethanes and haloacetic acids). This SDS method shall be performed by spiking a water sample with a disinfectant and holding the sample in the dark at the uniform formation conditions (UFC) specified in the ICR Manual for Bench- and Pilot-Scale Treatment Studies. Alternatively, the conditions selected for SDS evaluation may be those that most closely approximate the detention time and chlorine residual found in the distribution system at the location of verification testing. (Refer to the SDS Test Protocol in the QA/QC section of this Verification Testing Plan for further details.) The following UFC will be used for DBP formation testing:

- incubation period of 24 +/- 1 hours,
- incubation temperature of 20 +/- 1.0 °C,
- buffered pH of 8.0 +/- 0.2,
- 24-hour chlorine residual of 1.0 +/- 0.4 mg Cl_2/L.

9.5 Evaluation Criteria and Minimum Reporting Requirements

- Turbidity, particle concentrations and particle removal

⇒ plot graph of feed and filtrate turbidity at 4-hour intervals over time during each 30 day period of operation

⇒ plot graph of feed and filtrate particle concentrations at 4-hour intervals over time during each 30 day period of operation

⇒ plot graph of log removal of particles between feedwater and filtrate water at one-day intervals over time during each 30 day period of operation

⇒ perform mass balance calculations of total suspended solids through the membrane system and calculate concentrations of TSS in the backwash waste water. Calculated values shall be compared with actual measured TSS concentrations in backwash waste. (These backwash TSS concentrations may be an important consideration for residuals disposal.)

- Water quality and removal goals specified by the Manufacturer

⇒ provide feed and filtrate levels for TOC and UV_{254} absorbance in tabular form for each 30 day period of operation

⇒ provide feed and filtrate concentrations of any measured water quality parameters in tabular form for each 30 day period of operation

- Removal of indigenous bacteria (TC and HPC)

⇒ provide feed and filtrate levels for TC and HPC bacteria in tabular form for each 30 day period of operation

⇒ provide values for TC and HPC log removal in tabular form for each 30 day period of operation

- Removal of DBPs

⇒ provide feed and filtrate concentrations of TTHMs and HAA6 formed during SDS testing for each 30 day period of operation

10.0 TASK 4: REPORTING OF MEMBRANE PORE SIZE

10.1 Introduction

One mechanism by which low pressure membranes can remove microorganisms from water is physical sieving. Those organisms that are larger than the largest “pore size” of the membrane are retained by the membrane; those that are smaller than the pore size pass through the membrane into the filtrate. Quantification of the membrane pore size distribution is one critical factor in assessing whether a membrane has the potential to remove a microorganism from a feedwater. MF manufacturers report a "nominal" pore size, a size above which a specified percentage of particles of a certain nature are rejected under select conditions.

10.2 Objectives

The objective of this task is to report the 90 percent and maximum pore size for the membrane tested.

10.3 Work Plan

Membrane Manufacturers will have determined the pore size distribution for their membranes. The 90 percent and maximum pore size shall be reported and the general methods used for determining the values shall be discussed.

11.0 TASK 5: MEMBRANE INTEGRITY TESTING

11.1 Introduction

Monitoring of membrane integrity is necessary to ensure that an adequate barrier is continuously being provided by the membrane surface. In this task, existing methods of direct and indirect membrane integrity monitoring are identified and explained. These described techniques may include, but are not limited to:

11.1.1 Direct Monitoring Methods

- air pressure-hold testing,
- diffusive air flow testing,
- bubble point testing,
- sonic wave sensing.

11.1.2 Indirect Monitoring Methods

- particle counting,
- particle monitoring.

11.2 Experimental Objectives

The objective of this task is to demonstrate the methodology to be employed for monitoring membrane integrity and to verify integrity of membrane modules. Demonstration of the efficacy of either direct or indirect monitoring techniques is a requirement of this task.

11.3 Work Plan

The Field Testing Organization shall clearly describe the most appropriate methods for monitoring of membrane integrity in the Field Operations Document. The techniques listed above are intended to serve as examples of both direct and indirect methods for monitoring membrane integrity. These direct and indirect monitoring methods should be used together to provide consistent and sensitive evaluation of membrane system integrity.

11.3.1 Direct Monitoring Methods

Air Pressure-hold Test: The air pressure-hold test is one of the direct methods for evaluation of membrane integrity. This test can be conducted on several membrane modules simultaneously; thus, it can test the integrity of a full rack of membrane modules used for full-scale systems. Minimal loss of the held pressure (generally less than 1 psi every 5 minutes) at the filtrate side indicates a passed test, while a significant decrease of the held pressure indicates a failed test.

Diffusive Air Flow Test: The diffusive air flow test uses the same concept of the air pressure-hold test, but is performed by monitoring the displaced liquid volume due to the leaking air from compromised fiber(s). This test is more sensitive than the air pressure test because it is technically easier and is more accurate for measurement of small variations in liquid volume rather than small variations in air pressure.

Bubble Point Test: Bubble point testing can identify the fiber or seal location that is compromised in a membrane module. The test is typically performed after the compromised module is identified by a sonic sensor or any other monitoring method. After identifying the compromised fiber, it can then be isolated from the module by adding an epoxy glue to its inlet, or by inserting a pin with the same fiber diameter at the fiber inlet and outlet edges.

Sonic Sensing: Sonic sensors may also be used to detect the integrity of the membrane modules. The equipment consists of a sound wave sensor attached to a headphone. The headphones are manually placed at the top, middle, and bottom of the membrane module during the air-pressure hold test to detect any sound waves created by potential air bubbles leaking through a damaged fiber. The difference in audio sound between an intact and a compromised membrane may be identified by the pilot operators. Sonic sensing is only a qualitative tool for detecting loss of membrane fiber integrity, and therefore this test must be followed by a more quantitative method for evaluation of membrane integrity.

11.3.2 Indirect Monitoring Methods

Indirect methods of monitoring membrane integrity are those that do not evaluate the membrane itself, but rather use a surrogate parameter (such as particles) for assessing the membrane's condition. Continuous monitoring of particles in the filtrate stream is an indirect method for evaluating treatment reliability.

Several particle detection devices may be used for monitoring quality of the filtrate stream in terms of particles in the filtrate stream including: on-line and batch particle counters, and on-line particle monitors.

Particle Counting: Refer to Task 7, QA/QC for particle counting methodology.

Particle Monitoring: Particle monitoring is based on dynamic light obscuration. The instrument measures fluctuations in intensity of a narrow light beam which is transmitted through the sample. A fluctuating AC signal from a constant DC signal is measured by a detector and amplified. The monitor does not count particle sizes, but rather provides an index (ranging from 0 to 9,999) of the water quality. No calibration is required for this instrument since the output is a relative measurement of water quality. The potential advantages of this monitor is its low cost and ease of operation compared to particle counters.

11.4 Evaluation Criteria and Minimum Reporting Requirements

- criteria established by the Manufacturer and the designated Field Testing Organization in selection of the integrity testing method

⇒ plot table of membrane integrity results as appropriate

⇒ plot graph of integrity test results over time where appropriate for selected methodology

12.0 TASK 6: DATA HANDLING PROTOCOL

12.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheets and manual recording of operational parameters for the membrane equipment on a daily basis.

12.2 Experimental Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the Field Testing Organization provides sufficient and reliable operational data for the NSF for verification purposes.

12.3 Work Plan

The following protocol has been developed for data handling and data verification by the Field Testing Organization. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of pilot-testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of membrane equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially-prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the Field Testing Organization at least once per week during each seasonal one-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Pilot operating logs shall include a description of the membrane equipment (description of test runs, names of

visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each membrane test run) shall be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to state-certified or third party- or EPA-accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.0 TASK 7: QUALITY ASSURANCE/QUALITY CONTROL

13.1 Introduction

Quality assurance and quality control of the operation of the membrane equipment and the measured water quality parameters shall be maintained during the verification testing program.

13.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during the Equipment Verification Testing Program. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

13.3 Work Plan

Equipment flowrates and associated signals should be documented and recorded on a routine basis. A routine daily walk through during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to confirm that any chemicals are being fed at the defined flowrate into a flowstream that is operating at the expected flowrate, such that the chemical concentrations are correct. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e. flowrate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

13.4 Daily QA/QC Verifications:

- Chemical feed pump flowrates (verified volumetrically over a specific time period)
- In-line turbidimeters flowrates (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench model
- Batch and in-line particle counters flowrates (verified volumetrically over a specific time period).

13.5 QA/QC Verifications Performed Every Two Weeks:

- In-line flowmeters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).

13.6 QA/QC Verifications Performed Each Testing Period:

- In-line turbidimeters (clean out reservoirs and recalibrate)
- Differential pressure transmitters (verify gauge readings and electrical signal using a pressure meter)
- Tubing (verify good condition of all tubing and connections, replace if necessary)
- Particle Counters (perform microsphere calibration verification)

13.7 On-Site Analytical Methods

The analytical methods utilized in this study for on-site monitoring of raw water and filtered water quality are described in the section below. In-line equipment is recommended for its ease of operation and because it limits the introduction of error and the variability of analytical results generated by inconsistent sampling techniques. In-line equipment is recommended for measurement of turbidity and for particle counting for feed water and is required for measurement of turbidity and for particle counting for filtered water.

13.7.1 pH

Analyses for pH shall be performed according to Standard Method 4500-H^+. A 2 point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

13.7.2 Temperature

Readings for temperature shall be conducted in accordance with Standard Method 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every 0.1 °C, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1°C to +51°C, subdivided in 0.1 °C increments, would be appropriate for this work.)

13.7.3 Turbidity Analysis

Turbidity analyses shall be performed according to Standard Method 2130 or EPA Method 180.1 with either an in-line or bench-top turbidimeter. In-line turbidimeters shall be used for measurement of

turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be used for measurement of the feedwater (and concentrate where applicable).

During each verification testing period, the in-line and bench-top turbidimeters shall be left on continuously. Once each turbidity measurement is complete, the unit shall be switched back to its lowest setting. All glassware used for turbidity measurements shall be cleaned and handled using lint-free tissues to prevent scratching. Sample vials shall be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

13.7.3.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument shall serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of verification testing and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples shall consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity. For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion in a warm water bath for approximately 30 seconds.

13.7.3.2 In-line Turbidimeters. In-line turbidimeters shall be used for measurement of turbidity in the filtrate water during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments, the readings should be comparable. Should the comparison suggest inaccurate readings, then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

13.7.4 Particle Counting

In-line particle counters shall be employed for measurement of particle concentrations in filtrate waters. However, either a bench-top or an in-line particle counter may be used to measure particle concentrations in the feedwater, concentrate (where applicable) and pretreated waters (where applicable). Laser light scattering or light blocking instruments are recommended for particle counting during verification testing. However, other types of counters such as coulter counters or Elzone counters may be considered for use

if they can be configured to provide continuous, in-line monitoring for the filtrate product water stream. The following discussion of operation and maintenance applies primarily for use of laser light blocking instruments.

The following particle size ranges (as recommended by the AWWARF Task Force) shall be monitored by both in-line and bench-top analytical instruments during the verification testing:

- 2-3 μm
- 3-5 μm
- 5-7 μm
- 7-10 μm
- 10-15 μm
- > 15 μm

The Field Testing Organization shall be required to document any problems experienced with the monitoring particle counting instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

Use of particle counting to characterize feedwater and filtered water quality is required as one surrogate method for evaluation of microbioloigcal contaminant removal.

13.7.4.1 Bench-top Particle Counters. All particle counting shall be performed on-site. The particle sensor selected must be capable of measuring particles as small as 2 μm. There should be less than a ten percent coincidence error for any one measurement.

Calibration. Calibration of the particle counter is generally performed by the instrument manufacturer. The calibration data will be provided by the manufacturer for entry into the software calibration program. Once the data has been entered it should be verified using calibrated mono-sized polymer microspheres. This calibration shall be verified at the beginning of each Verification Testing period. Additionally, calibrated mono-sized polymer microspheres in sizes of 2, 10, and 15 μm should be used for the verification. The procedure is as follows:

- Analyze the particle concentration in the dilution water;
- Add an aliquot of the microsphere suspension to the dilution water to provide a final particle concentration of approximately 50,000 particles per 25 mL (2,000 particles per mL), and then gently swirl the suspension;
- Promptly analyze a suspension of each particle size separately to determine that the peak of particle concentration coincides with the diameter of particles added to the dilution water;
- Prepare a cocktail containing all three microsphere solutions to obtain a final particle concentration of approximately 1,000 particles per mL of each particle size; and
- Promptly analyze this cocktail to determine that the particle counter output contains peaks for all of the particle sizes.

Maintenance. The need for routine cleaning of the sensor cell is typically indicated by: 1) illumination of the sensor's "cell" or "laser" lamps, 2) an increase in sampling time from measurement to measurement,

or 3) an increase in particle counts from measurement to measurement. During the pilot study, the sensor's "cell" and "laser" lamps and the sampling time will be checked periodically. The number of particles in the "particle-free water" will also be monitored daily.

Particle-Free Water System. "Particle-free water" (PFW) will be used for final glassware rinsing, dilution water, and blank water. This water will consist of de-ionized (DI) water that has passed through a 0.22-μm cartridge filtration system. This water is expected to contain fewer than 10 total particles per mL, as quantified by the on-site particle counter.

Glassware Preparation. All glassware used for particle counting samples shall consist of beakers designed specifically for the instrument being used. Glassware will be cleaned after every use by a triple PFW rinse. Sample beakers will then be stored inverted.

Dedicated beakers will be used at all times for unfiltered water (raw, pre-oxidized, flocculated), diluted unfiltered water, filtered water, and PFW. When several samples are collected from various pilot plant sampling points during one day, the appropriate beakers will be hand-washed as described above, and then rinsed three times with sample prior to collection.

Other materials in contact with the samples, including volumetric pipettes, volumetric flasks, and other glassware used for dilution, will also be triple-rinsed with both PFW and sample between each measurement.

Sample Collection. Beakers should be rinsed with the sample at least three times prior to sample collection for particle counting. Sample taps should be opened slowly prior to sampling. Sudden changes in the velocity of flow through the sampling taps should be avoided immediately prior to sample collection to avoid scouring of particles from interior surfaces. A slow, steady flow rate from the sample tap will be established and maintained for at least one minute prior to sample collection. The sample will be collected by allowing the sample water to flow down the side of the flask or beaker; thereby minimizing entrainment of air bubbles.

Dilution. The number of particles in the raw and pretreated waters (where applicable) is likely to exceed the coincidence limit of the sensor. If so, these samples will be diluted prior to analysis. In all cases, PFW will be used as dilution water. When necessary, dilutions will be performed as follows:

- Dilution water will be dispensed directly into a 500-mL volumetric flask;

- A volumetric pipette (i.e. 10-mL for a 50:1 dilution) will be used to collect an aliquot of the sample to be diluted (stock);

- The appropriate volume of the stock will be slowly added to the volumetric flask containing the dilution water;

- The volumetric flask will be slowly filled to the full-volume etch with dilution water;

- The volumetric flask will be inverted gently and then its contents will be poured slowly into the appropriate 500-mL flask for analysis.

During each of the above steps, care will be taken to avoid entrainment of air bubbles; thus, samples and dilution water will flow slowly down the side of containers to which they are added. Excessive flow rates through pipette tips, which can cause particle break-up, will be avoided by use of wide-mouth pipettes. Sample water will be drawn into and out of pipettes slowly to further minimize particle break-up.

Actual particle counts in a size range for diluted samples will be calculated based on the following formula:

$$Sample\ Particle\ Concentration = \frac{\{MP - (1 - X) \times PF\}}{X}$$

where MP is the measured particle concentration in the diluted sample, PF is the measured particle concentration in the particle-free water, and X represents the dilution factor. For a 25:1 dilution, the dilution factor would be 1/25, or 0.04. The expression for the dilution factor is provided by the following equation:

$$Dilution\ Factor = X = \frac{Volume\ Sample}{Addition\ of\ Volume\ Sample + Volume\ Dilution\ Water}$$

Particle Counting Sample Analysis. To collect samples for particle counting, at least 200 mL of each water sample to be counted (diluted or not) should be collected in the appropriate beaker. The beaker will be placed into the pressure cell and counting will take place in the "auto" mode of the instrument. Four counts will be made of each sample. The first count will serve to rinse the instrument with the sample; data from this count are discarded. Data from the subsequent three counts will be averaged, and the average value will be reported as the count for that sample.

13.7.4.2 In-line Particle Counters. In-line particle sensors selected for use must have capabilities for measurement of particles as small as 2 μm and have a coincidence error of less than ten percent. Methods for demonstration of coincidence error shall be provided by the particle counter instrument Manufacturer.

The sensors of the in-line units must also be provided with an updated manufacturer calibration. The calibration shall be verified by measurement of the individual and cocktail suspensions of the monospheres as described for the batch counter; however, in this case the samples must be fed in-line to the counters.

No dilution of the filtered water samples shall be conducted. The data acquired from the counters shall be electronically transferred to the data acquisition system. If it is known that a particular sensor will not be used for a period of several days or more, refer to the manufacturer recommendations for an appropriate storage protocol.

13.8 Organic Parameters: Total Organic Carbon and UV_{254} Absorbance

Samples for analysis of TOC and UV254 absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held, and shipped in accordance with Standard Method 5010B. Storage time before analysis shall be minimized, according to *Standard Methods*.

13.9 Microbial Parameters: Total Coliforms and Heterotrophic Plate Counts

Samples for analysis of Total Coliforms (TC) and Heterotrophic Plate Counts (HPC) shall be collected in bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by the state-certified or third party- or EPA-accredited laboratory the time specified for the relevant method. Laboratory shall keep the samples at approximately 4°C until initiation of analysis. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) or as total coliform densities per 100 mL. HPC densities shall be reported as colony forming units per milliliter (cfu/mL).

13.10 Inorganic Samples

Inorganic chemical samples, including, alkalinity, hardness, aluminum, iron, and manganese, shall be collected and preserved in accordance with Standard Method 3010B, paying particular attention to the sources of contamination as outlined in Standard Method 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

13.11 Simulated Distribution System (SDS) Test Protocol

The simulated distribution system (SDS) disinfection by-products (DBP) test simulates full-scale disinfection by spiking a water sample with a disinfectant and holding the spiked sample in the dark at a designated temperature and contact time. For this testing, one of two SDS approaches may be employed. The conditions selected for SDS evaluation may be those that most closely approximate the detention time and chlorine residual found in the distribution system at the location of verification testing. Alternatively, the uniform formation conditions (UFC) specified by the ICR may be adopted. The UFC, as specified under the ICR stipulate that the following set of conditions will be employed:

- incubation period of 24 +/- 1 hours,
- incubation temperature of 20 +/- 1.0 °C,
- buffered pH of 8.0 +/- 0.2,
- 24-hour chlorine residual of 1.0 +/- 0.4 mg Cl_2/L.

For each SDS sample, three incubation bottles will be set up. At the end of the incubation period, each sample will be analyzed for the final disinfectant residual and the sample with the residual closest to the 1.0 +/- 0.4 mg/L range will be used for specified DBP analyses.

One liter, amber colored bottles with Teflon lined caps will be used to store the SDS samples during incubation. These bottles will be stored in a temperature-controlled incubator at the specified temperature.

All glassware used for preparation of the reagents will be chlorine demand free. Chlorine demand free glassware will be prepared by soaking glassware in a 50 mg/L chlorine bath for a period of 24 hours. At the end of this time, all glassware will be rinsed three times with organic-free water that has a TOC concentration of less than 0.2 mg/L. Glassware will then be dried at room temperature for a period of 24 hours. During the drying process, bottle openings will be covered with aluminum foil to prevent contamination.

Reagents will be prepared as follows.

13.11.1 Chlorine Stock Solution Preparation

The stock solution is prepared by adding an estimated volume of 6% reagent-grade NaOCl into a 500-mL, chlorine demand free, bottle containing an estimated amount of organic-free water. To minimize the dilution error, the chlorine stock solution is required to be at least 50 times stronger than the chlorine dose required.

13.11.2 Preparation of Additional Chemicals

Refer to Standard Method 4500-Cl F for the preparation method of DPD indicator, FAS standard and buffer solution. The phosphate buffer solution should be prepared as instructed in Standard Method 4500-Cl F.

13.11.3 Sample Collection and Incubation

The samples will be collected in a 1-L amber bottle and stored in the dark at the predetermined temperature. Samples will be adjusted to the designated pH and chlorine residual for the distribution system at the chosen site. In the case that the UFC are adopted for SDS testing, the samples will be adjusted to pH 8.0 +/- 0.2 using 1M HCl or NaOH and will then be dosed with the appropriate dosage of chlorine to yield a chlorine residual of 1.0 +/- 0.4 mg Cl_2/L after the specified 24-hour storage period. The samples will be capped head-space free and stored for the appropriate time (24 hours for UFC) in the dark at the appropriate incubation temperature.

13.11.4 Analytical Measurements

Residual free chlorine measurements will be conducted according to *Standard Methods* 4500-Cl G. DPD Colorimetric Method. Specific parameters to be measured and recorded are outlined in the specific task descriptions.

14.0 TASK 8: MICROBIAL REMOVAL (OPTIONAL)

14.1 Introduction

Absolute removal of *Giardia* and *Cryptosporidium* has been well documented for only a selected number of MF and UF processes. Virus removal capabilities have not been well documented extensively for membrane processes. In this task, the effectiveness of membrane processes for microbial removal shall be evaluated by use of seeding studies. It should be noted that all protozoa and virus verification testing of membrane equipment for microbial removal shall be considered an optional task in this NSF Equipment Verification Testing Plan. The optional seeding studies shall be conducted with protozoa (*Giardia* and *Cryptosporidium*) and/or MS2 virus, and shall be performed during the required test runs conducted for Task 1.

14.2 Experimental Objectives

The experimental objective of this task is to characterize the membranes in terms of microbial removal. The type of seeding studies (protozoa, viruses or both) to be conducted as a part of this task will be left to the discretion of the Manufacturer.

14.3 Work Plan

Microbial challenge experiments shall be conducted only at pilot scale to assess the effectiveness of the membrane to achieve microbial removal. During the seeding studies, the Field Testing Organization shall conduct the microbial seeding studies in the field as described in the following procedures and sample collection sections. The Field Testing Organization shall then submit collected seeding water samples to a state-certified or third party- or EPA-accredited laboratory for microbial testing.

14.3.1 Organisms Employed for Pilot-Scale Challenge Experiments

Table 5 presents the different microorganisms that may be used for the optional pilot-scale microbial rejection studies. Two protozoan cysts and one virus were identified for use in these optional seeding studies. These organisms were chosen to provide some variety in the types and sizes of microorganisms in order to indicate the range of membrane microbial removal capabilities. *Giardia* cysts were selected since this microorganism is one of the driving forces behind the SWTR. The model microorganism used may either be *Giardia muris*, a non-pathogenic species, or *Giardia lamblia*, a pathogenic species. *Cryptosporidium* is another important protozoan that is potentially targeted for regulation in the future. *Cryptosporidium parvum* is recommended for use in these studies.

Table 5
Microorganisms Recommended for Microbial Seeding

Microorganism	Model	Source
Protozoa	*Giardia muris* *Cryptosporidium parvum*	seeded seeded
Virus	MS2 bacteriophage	seeded

MS2 bacterial virus was identified for use as the model virus for the microbial challenge studies. MS2 bacteriophage is the virus of choice for challenge studies because it is similar in size (0.025 μm), shape (icosahedron) and nucleic acid (RNA) to polio virus and hepatitis. This bacterial virus is the suggested organism to use in the SWTR Guidance Manual when conducting studies of microbial removal (USEPA, 1989).

It is recognized that in many cases it may not be possible to employ viable protozoan cysts and oocysts for seeding studies, depending upon where the equipment verification is being performed. In such a case, *Cryptosporidium* organisms fixed in no more than 10% formalin may be used. *Giardia* organisms fixed in no more than 5% formalin may be used. Alternatively, the organisms may be heat-fixed. Introduction of surrogates or alternatives for formalin- or heat-fixed protozoa and MS2 virus to this testing plan shall be based upon peer-reviewed studies and proven experimental methodologies and

shall only be allowed after approval from NSF. Organism stocks received from appropriate suppliers shall be stored under refrigeration in the dark at 4°C until use in the seeding studies. Aliquots for use in each seeding study shall then be delivered on ice to the pilot plant on the day of the testing.

14.3.2 Microbial Seeding Protocols

Microbial challenges shall be conducted as batch seeding tests, with one seeding study conducted per testing period. In the batch testing mode, each microorganism to be used for challenge testing shall be seeded to a constant volume of feedwater (potentially 50 to 200 gallons). Sufficient volume of stock suspension shall be created in the seeding tank to sustain membrane operation for a minimum of 30 minutes. For the protozoa seeding studies, the final seeding concentration in the feed water tank should be high enough to demonstrate at least 4 logs removal of *Giardia* and *Cryptosporidium*. For the virus seeding studies, the final seeding concentration in the feed water tank should also be high enough to demonstrate at least 4 logs removal of viruses.

The seeding experiments shall be conducted under the operating conditions in which the microorganisms would be most likely to penetrate the membrane. These conditions may include the high flux employed during the testing period. Initiation of the seeding study shall occur immediately after backwashing the membrane. Furthermore, the membrane seeding studies should be performed as soon as possible following a chemical cleaning procedure. In the case that the membrane equipment is operated with automatic backwash routines, the addition of seed microorganisms should be performed immediately at the conclusion of a backwash routine in order to evaluate microbial removal in the absence of a cake layer on the membrane surface. The frequency of backwash may need to be adjusted during microbial challenge in order to allow sufficient time for sample collection.

The feed suspension of protozoa or viruses shall be prepared in the seeding tank by adding the concentrated stock suspension(s) of organisms into a feedwater reservoir. The reservoir shall be completely mixed during preparation of the seeded feedwater and throughout the filtration period. After the addition of protozoa or viruses to the seeding tank and before the initiation of filtration, samples shall be collected to establish the initial titer of the microorganisms. Once filtration has begun, transmembrane pressure, filtrate flux and recirculation rate (where appropriate) shall be recorded. Sample volumes of the feedwater, filtrate water and backwash water shall recorded. An EPA-accredited laboratory shall be selected for analysis of appropriate microbial species, and sample volumes shall be processed according to the instruction provided by the EPA-accredited laboratory. At the end of sample preparation, the prepared samples shall be shipped to the EPA-accredited laboratory for analysis.

During the protozoa studies, a minimum of three replicates of the filtered water samples shall be prepared per seeding study (per season) for analysis by the EPA-accredited laboratory. During MS2 viral seeding studies, a minimum of one sample from the feedwater, three samples from the filtrate water and one sample from the backwash water shall be collected. The first permeate sample for viral seeding studies shall be collected within the first 30 seconds of initiating filtration of the seeded waters, and subsequent samples shall be collected at 10 to 15 minute intervals. Each sample shall be collected in sterile 250 mL bottles. Bottles shall be stored at 1°C and processed within 24 hours.

14.4 Analytical Schedule

14.4.1 Water Quality Sampling

During microbial seeding studies, sampling of feedwaters and filtrate waters shall be performed with daily measurement of temperature, pH, turbidity and particles.

14.4.2 Operational Data Collection

Operational data, as required by Task 1 shall be collected at the time of each seeding experiment.

14.5 Evaluation Criteria and Minimum Reporting Requirements

- Removal of *Giardia* and *Cryptosporidium*
- ⇒ provide feed water and filtrate levels of *Giardia* and *Cryptosporidium* in tabular form
- ⇒ create bar chart of log removal of microorganisms seeded (*Giardia* and *Cryptosporidium*)
- Removal of virus
- ⇒ provide influent and effluent levels of *virus* in tabular form
- ⇒ create bar chart of log removal of microorganisms seeded (*viruses*)

15.0 TASK 9: RAW WATER PRETREATMENT (OPTIONAL)

15.1 Introduction

In most membrane systems employed for microbial and particle removal, there are usually no chemicals added to the raw water before filtration. However, some Manufacturers may wish to be verified by NSF for a pretreatment technique that may not be considered a necessary process of the membrane technology for microbiological and particulate removal. As such, pretreatment can be employed to extend membrane operational time or remove selected contaminants. For example, some membranes are capable of absolute removal of microorganisms, but provide little or no removal of DBP precursors. Addition of a coagulant or adsorbent to the raw water may enhance the removal of these precursors.

Verification of optional or separable pretreatment techniques shall constitute an optional task in the verification testing of membrane equipment. This Task shall be conducted for an additional month of pilot testing and shall be considered a discretionary supplement to the NSF Equipment Verification Testing Plan that is included by the Field Testing Organization. In cases where a pretreatment technique is considered an integral or inseparable part of the function of the membrane system, no additional testing of system pretreatment capabilities would be necessary.

15.2 Experimental Objectives

The objectives of this task are to demonstrate membrane performance following a selected pretreatment technique and determine the efficacy of pretreatment for the membrane equipment tested, based upon the Manufacturer's treatment goals. For the purposes of this microbiological and particulate contaminant removal test plan, membrane operation and particulate removal shall be monitored as described in the Analytical Schedule below. For additional monitoring for removal of selected contaminants, however, the appropriate NSF Verification Protocols and Test Plans should be consulted. For example, if the optional

pretreatment selected is designed to achieve removal of precursors to disinfection by-products, the NSF Protocol and Test Plan for Removal Precursors to DBPs should be consulted and the analytical schedule followed as a demonstration of equipment performance.

15.3 Work Plan

The focus of this task is to determine the relative rates of flux decline and performance capabilities of the membranes as a function of the selected pretreatment process. Appropriate pretreatment techniques shall be specified by the Field Testing Organization.

15.4 Analytical Schedule

The pretreatment testing schedule shall be determined by the Field Testing Organization. However, each pretreatment technique should be tested for a minimum of one month, preferably during the month immediately following the required month of testing for Tasks 1 through 3.

15.4.1 Raw, Pretreated Feed and Filtrate Water Characterization

For this test plan addressing removal of microbiological and particulate contaminants, monitoring shall be conducted to provide a baseline of the solids removal capabilities of the pretreatment and membrane system. At the beginning of each membrane testing period at a single set of operating conditions (and thereafter with indicated frequency), the raw water, the pretreated feedwater and the filtrate water shall be characterized by measurement of the following water quality parameters (as indicated in Table 3):

- alkalinity (once per month)
- hardness (once per month)
- total suspended solids (twice per month)
- total dissolved solids (twice per month)
- total organic carbon (once per month*)
- $UV_{254\ nm}$ absorbance (once per month*)
- Total coliform (TC) and heterotrophic plate count (HPC) bacteria (once per week)
- temperature (daily)
- pH (monthly*)
- filtrate water turbidity and particle concentrations (daily)
- raw water and pretreated feedwater turbidity and particle concentrations (daily)

*more frequent monitoring may be performed at the discretion of the Manufacturer or FTO.

Additional monitoring may be required for characterization of the raw, pretreated feed and filtrate waters, in the case that protocols and test plans for other selected contaminants are employed for demonstration of pretreatment removal capabilities.

15.4.2 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during each period of membrane testing, as required in Table 3. For verification of particulate removal, turbidity and particle concentrations in filtrate waters shall be monitored continuously using either batch or in-line analytical instruments. Grab samples of raw waters and pretreated feedwaters shall be measured by the NSF-qualified Field Testing Organization daily for temperature, turbidity and particle concentrations using bench-top analytical

instruments. The specific particle size ranges to be monitored by both in-line and bench-top analytical instruments during the verification testing are indicated in Task 7, the QA/QC section.

Total suspended solids shall be monitored every other week and results of this analysis will be used to construct a mass balance of suspended solids through the membrane system. Monitoring of water quality characteristics such as TOC and UV_{254} absorbance shall be performed on a monthly basis to provide a general background on the source water character and quality for each testing period. Additional sampling and data collection may be performed at the discretion of the Field Testing Organization. Sample collection frequency and protocol shall be defined by the Field Testing Organization in the Field Operations Document.

On a weekly basis, samples of raw water, pretreated feedwater and filtrate shall be collected for analysis of indigenous bacterial densities including: total coliform (TC) and heterotrophic plate count (HPC). Collected samples shall be placed in a cooler with blue ice to be shipped with an internal cooler temperature of approximately 2-8°C to the state-certified or third party- or EPA-accredited analytical laboratory. Samples shall be processed for analysis by the state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 2-8°C until initiation of analysis. TC densities will be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities will be reported as colony forming units per milliliter (cfu/mL).

15.4.3 Feedwater Quality Limitations

The characteristics of raw waters and pretreated feedwaters encountered during the one-month testing period shall be explicitly stated in reporting the membrane flux and recovery data. Accurate reporting of such feedwater characteristics as temperature, turbidity, TSS, pH, alkalinity and hardness is critical for the Verification Testing Program, as these parameters can substantially influence membrane performance on a seasonal basis.

15.5 Evaluation Criteria and Minimum Reporting Requirements

- Transmembrane pressure (P_{tm})
- ⇒ Plot graph of transmembrane pressure over time for each 30 day period of operation
- Rate of specific flux decline
- ⇒ Plot graph of specific flux over time for each 30 day period of operation
- Cleaning frequency
- ⇒ Provide table of intervals between chemical cleaning episodes during each 30 day period of operation
- Flux recovery
- ⇒ Provide table of post cleaning flux recovery during each 30 day period of operation
- Turbidity, particle concentrations and particle removal
- ⇒ plot graph of feed and filtrate turbidity over time during each 30 day period of operation
- ⇒ plot graph of feed and filtrate particle concentrations over time during each 30 day period of operation
- ⇒ plot graph of log removal of particles between feedwater and filtrate water at one-day intervals over time during each 30 day period of operation
- ⇒ perform mass balance calculations of total suspended solids through the membrane system and calculate concentrations of TSS in the backwash waste water. Calculated values shall be compared with actual measured TSS concentrations in backwash waste. (These backwash TSS concentrations may be an important consideration for residuals disposal.)

- Water quality and removal goals specified by the Manufacturer

⇒ provide feed and filtrate levels for TOC and UV_{254} absorbance in tabular form for each 30 day period of operation

⇒ provide feed and filtrate concentrations of any selected water quality parameters in tabular form for each 30 day period of operation

- Removal of indigenous bacteria (TC and HPC)

⇒ provide feed and filtrate levels for TC and HPC bacteria in tabular form for each 30 day period of operation

⇒ provide values for TC and HPC log removal in tabular form for each 30 day period of operation.

16.0 OPERATION AND MAINTENANCE

The Field Testing Organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria for O&M Manuals for membrane filtration package plants that are designed to achieve removal of microbiological and particulate contaminants.

16.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- pressure gauges
- backwash controls
- flow meters
- air compressors
- chemical feeder systems
- mixers
- motors
- instruments, such as streaming current monitors or turbidimeters
- water meters, if provided

The Manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- in-line static mixers
- tubing and hoses

16.2 Operation

The Manufacturer should provide readily understood recommendations for procedures related to proper operation of the package plant equipment. Among the operating aspects that should be discussed are:

Filtration:

- control of feed flow to the membrane system
- measurement of inlet/outlet pressures and filtrate flows

- measurement of transmembrane pressure changes during filter run
- feed flow control in response to temperature changes

Membrane backwashing:

- programming automated frequency
- proper backwash venting and disposal
- appropriate backwash rate (if applicable)
- monitoring during return of filter to service

Chemical cleaning:

- selection of proper chemical washing sequence
- proper procedures for dilution of chemicals
- monitoring of pH through chemical cleaning cycle
- rinsing of membrane system following chemical clean
- return of filter to service

Chemical feeders (in the case that chemical pretreatment is applied):

- calibration check
- settings and adjustments -- how they should be made
- dilution of chemicals and polymers -- proper procedures

Monitoring and observing operation:

- observation of feedwater or pretreated water turbidity
- observation of transmembrane pressure increase between backwashes
- filtered water turbidity
- filter head loss
- what to do if turbidity breakthrough occurs

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- no raw water (feedwater) flow to plant
- can't control rate of flow of water through package plant
- valving configuration for direct flow and cross-flow operation modes
- poor raw water quality (raw water quality falls outside the performance range of the equipment)
- poor filtrate quality
- failed membrane test
- low pump feed pressure
- automatic operation (if provided) not functioning
- filtered water turbidity too high
- head loss builds up excessively rapidly
- reduced filtrate flux
- machine will not start and “Power On” indicator off
- machine will not start and “Power On” indicator on
- pump cavitation
- valve stuck or won't operate
- no electric power

It is also recommended that the Manufacturer add a toll free number to the O&M manual for technical assistance on operation and maintenance of the equipment.

The following are recommendations regarding operability aspects of package plants that are designed to achieve removal of microbiological and particulate contaminants. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of package plant testing when the testing is done under the NSF Verification Program.

During Verification Testing and during compilation of historical package plant operating data, attention shall be given to package plant operability aspects. Among the factors that should be considered are:

- fluctuation of flow rates and pressures through membrane unit -- the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?)
- presence of devices to aid the operator with flow control adjustment and chemical dosage selection:
  - influent and filtered water continuous turbidimeters provided?
  - continuous particle counter provided on membrane filtered water?
- can backwash be done automatically?
- if automatic backwash provided, could it be initiated by:
  - reaching a set value for head loss?
  - reaching a set value for filtered water turbidity?
  - a preset automatic timer?
- does remote notification to operator occur when backwash happens?
- can operator observe backwash?
- does plant have multiple feed points for chemicals:
  - for pH adjustment?
  - for coagulant chemical feed?
  - for antiscalant addition?
- is transmembrane pressure measurement provided?
- is rate of flow of raw water measured?
- is chemical feed paced with raw water flow?
- is backwash rate of flow measured and variable?
- is backwash duration (time) variable?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability should be dealt with in the portion of the reports that are written in response to Tasks 1 & 2 of the Membrane Filtration Test Plan addressing the Removal of Microbiological and Particulate Contaminants.

17.0 REFERENCES

Partnership for Safe Water, AWWA, USEPA, AMWA, ASDWA, NAWC, AWWARF, 1995.

Streeter, V.L. and E.B. Wiley. 1985. Fluid Mechanics, 8th ed. New York, McGraw Hill Book Company.

USEPA, 1989. Guidance Manual for Compliance with Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Sources, Cincinnati, OH. Science and Technology Branch.

USEPA, 1990. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Waters. American Water Works Association, Washington, D.C.

USEPA, 1996. ICR Manual for Bench- and Pilot-Scale Treatment Studies. Office of Ground Water and Drinking Water, Cincinnati, OH. Technical Support Division.

APPENDIX 2A

STATE-SPECIFIC VERIFICATION TESTING REQUIREMENTS

Ohio:

- It would be informative to determine maximum membrane pore size at the end of the testing (i.e., end of month 11) as well as at the beginning (month 1).

- Alkalinity and hardness measurement should be increased to daily.